FINAL REPORT

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Assessment of Alternative Environmentally Sustainable Sources of Energy Generation- A river basin study in India.

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1 Introduction

Background

Energy, environment and economy are critical sectoral issues on the action plan agenda of policy planners and decision makers of all countries, today. Quasi-static equilibrium between energy production and demand by virtue of environmentally clean technologies is an indicator of economic health of a country. The stocks of conventional fossil fuels all over the world have been depleting rather fast over the past few years and hence there have wide spread efforts to explore non-conventional and environmentally sustainable alternative sources of energy*. In India, industrial effluents and domestic sewage have been used for quite some time now as a source of energy, though the focus on harnessing energy from municipal waste has been rather recent. The *'waste to energy'* concept serves the twin purposes of managing the wastes in a safe scientific manner and generating the much in demand energy simultaneously. Research and pilot scale studies have been conducted nationally and internationally to develop appropriate technologies for energy recovery from waste and success has been achieved to a considerable extent.

Presently there are four technologies existing to generate energy from municipal solid wastes (MSW) - incineration, pelletization, landfill gas recovery and anaerobic digestion. Anaerobic digestion (AD) is also suitable for energy production from liquid wastes - both domestic and industrial.

For municipal solid waste, in India, we have two pilot level pelletization plants operating. One is in Mumbai set up with the support of Department of Science and Technology, Government of India and the other is in Bangalore. This technology could serve as a good option for energy recovery in the future, but more work in terms of R&D and pilot plants will have to take place before the same can be utilized at commercial levels. Then, incineration is something not suitable for the Indian waste due to its low calorific value and high moisture content. One incinerator had been set up in Delhi in 1980's to manage the city's waste but it had to be shut down within few months as the energy produced was very low and far more energy was being consumed in running the plant, resulting in heavy losses. Landfill gas recovery is a distant dream in Indian context as the prevailing practice is to dump waste in an uncontrolled manner and we have not even taken the first step towards this technology i.e. to have a sanitary landfill site. Thus the only *'waste to energy'* disposal option left is that of anaerobic

* Though there are quite a few alternative sources of energy generation other than the conventional fuels, this study has been restricted to *'wastes'* only due to the short duration of the study.

digestion, which has had widespread application worldwide and is in the initial stages in country at the moment. Though there is only one anaerobic digester(AD) operating in Pune today, using vegetable market waste as the feed, there are pilot scale studies being conducted.

Domestic sewage can be treated by the anaerobic digestion technique to generate biogas and the effluent produced can be discharged either on land or in a river without exceeding the levels of pollutant set up by CPCB (Central Pollution Control Board)— the apex regulatory body on pollution control in the country. Most of the upcoming domestic effluent treatment plants in India are based on the anaerobic technology and the traditional aerobic methods are slowly being phased out.

India has a large potential for implementation of anaerobic technology in industrial sector. Industries such as distilleries, pulp and paper, tanneries and food processing have high organic content in their effluents and hence are most suitable to have anaerobic effluent treatment plants.

Currently there are only two full- scale anaerobic plants for treatment of pulp & paper mill effluent in the country. Though many large- scale pulp and paper mills have aerobic treatment facilities for their effluent, most of these are inadequate or are performing unsatisfactorily. The CSTR (completely stirred type reactor) installed at Pudumjee Pulp and Paper Mills, Pune treats about 0.25 million litres of effluent per day with a BOD (biochemical oxygen demand) and COD (chemical oxygen demand) removal of approximately 85% and 65% respectively (data collected during a personal visit in 1998). A 4.58 MLD (million litre per day) wastewater treatment plant based on UASB (Upflow anaerobic sludge blanket) technology has been successfully commissioned at Satin Paper mills, Punjab *(BioEnergy News* 1997).

Anaerobic treatment technologies for tannery effluent are available in India, irrespective of the nature of effluent generated (this depends on type of process used in the industry- chrome tanning, vegetable tanning or mixed type of tanning). In one of the commercial tanneries at Kanpur a 10,000 litre capacity UASB reactor is operating with a designed HRT(hydraulic retention time) of 12 hours. The plant is able to achieve 70% reduction in COD (Rajamani, Suthantharajan, Ravindranath et al. 1995).

Next are the dairy industries which too produce large amounts of wastewater suitable for energy recovery after anaerobic treatment. Dairy effluent consists of high, fast-degrading organic matter. Extensive pilot plant studies have been carried out in the state of Maharashtra to develop anaerobic treatment process for the wastewater (Amritkar 1995. cited in Tare, Vinod, Mansoor et al. 1997).
A case study of a milk-processing unit in Maharashtra showed that through anaerobic treatment, savings to the tune of Rs. 25 million per year could be achieved in the state of Maharashtra alone (Amritkar 1995).

A large number of anaerobic reactors of different designs have been installed for effluent treatment in distillery and sugar industry sector. These are UASB (Libin 1997), hybrid reactor (Bardiya, Hashia and Chandna 1995) and fixed film reactor (Manihar 1995).

Objectives of the study

The objectives of this study were:

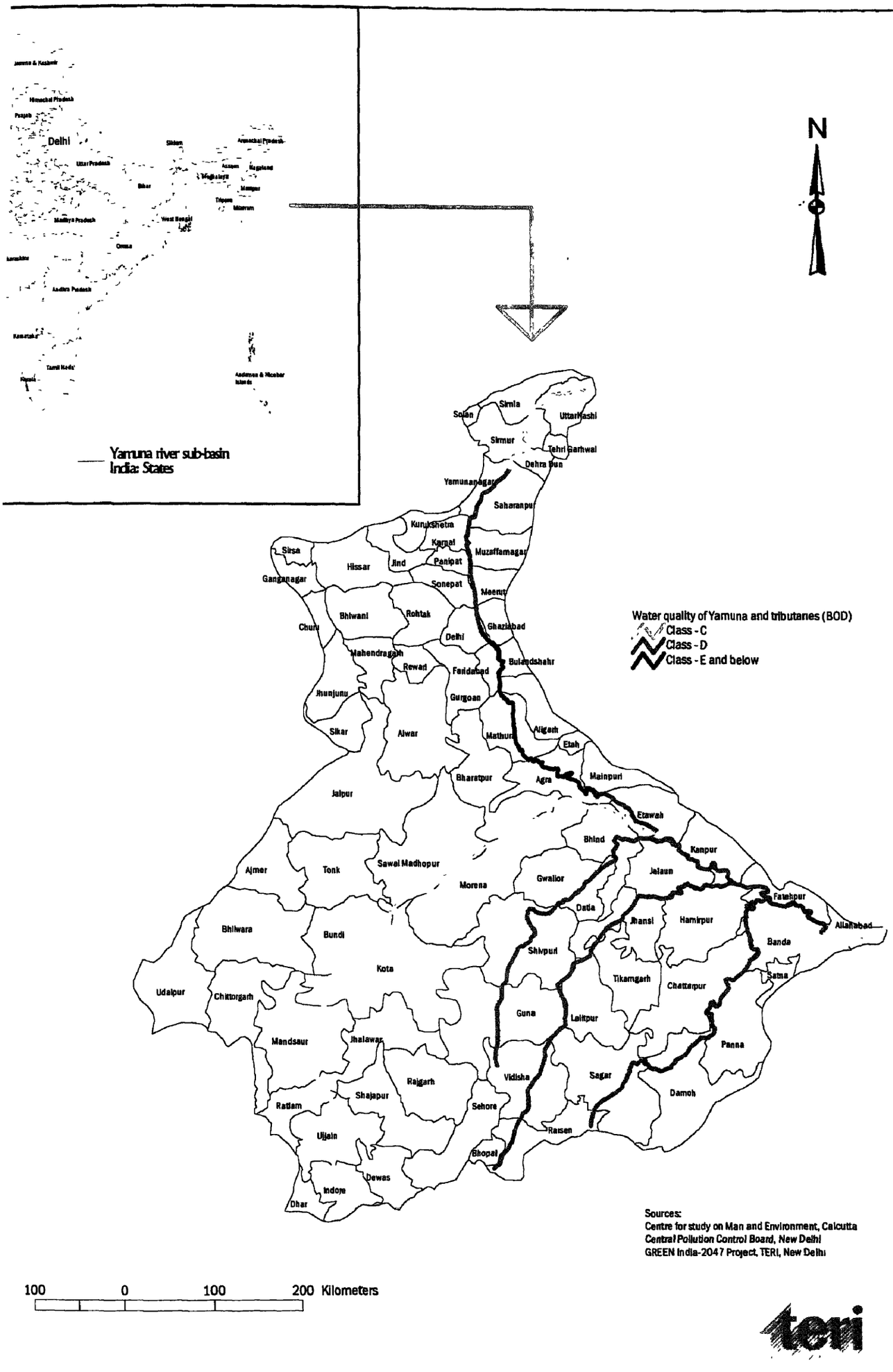
- Estimation of energy generation potential from wastes- municipal waste, domestic sewage and industrial effluents in Yamuna sub-basin, with district as the minimum spatial unit.
- Representation of energy potential on a map using GIS. The map would cover the generation potential only from municipal waste and sewage.
- Recommendations for suitable technology interventions to tap the energy estimated above.
- Estimation of pollution abatement by adopting technologies which would convert waste into energy in the basin.

The Yamuna sub-basin

River Yamuna is the major tributary of river Ganga and has a watershed area of 345, 848 square kilometers covering 6 states. The river originates from Yamunotri glacier in the Mussorie range of lower Himalayas at an elevation of 6378 m above sea level at Uttar Kashi and merges finally into river Ganga at Allahabad in Uttar Pradesh. After Independence, large scale industrialization and urbanization has occurred along the river Yamuna resulting in its emergence as one of the most productive belts in the country. However this has also resulted in deteriorating water quality of the river due to heavy abstraction of water for irrigation, domestic water supply and industrial usage from the river and also discharge of untreated and often heavily polluted domestic sewage and industrial effluents into it. It is estimated that 80% of the pollution of the river is due to domestic sewage and rest 20% is from industrial sources.

Yamuna sub-basin (Map 1.1) is a part of Ganga basin. It stretches over an area of 11,000 sq. kms. and covers about 81 odd districts (Annexure 1) in 6 states of Madhya Pradesh, Himachal Pradesh, Uttar Pradesh, Haryana, and Rajasthan and Delhi. Total no. of towns and cities falling in these districts is about 675 out of which 62 are Class 1* and 67 are Class 2† towns.

* Population above 100,000
† Population in the range of 50,000 and 100,000



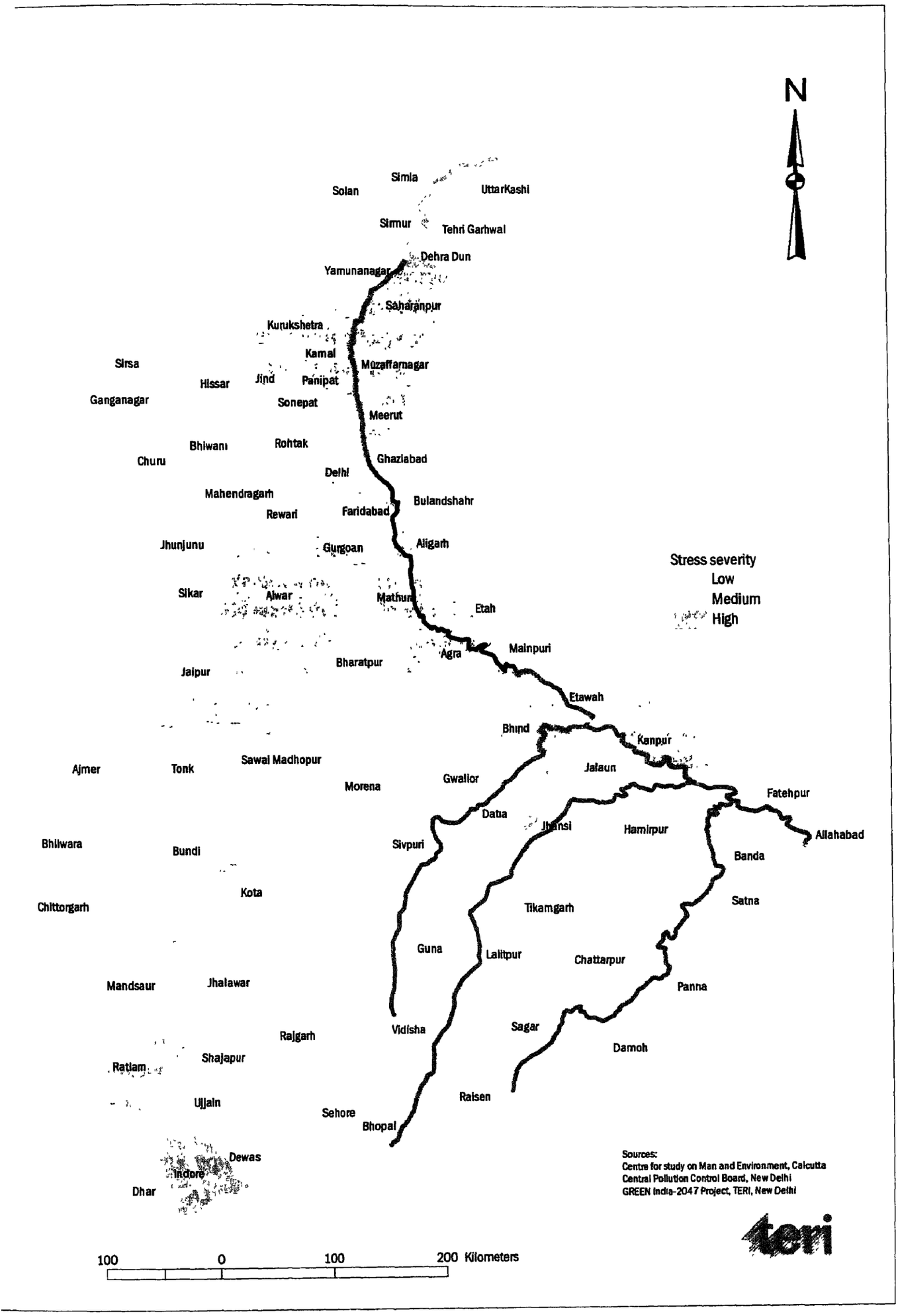
Map 1.1 Location map of Study area: Yamuna river sub-basin

Aethodology

The study area comprised of 81 districts. Data on population, wastewater characteristics and generation, treatment type and solid waste generation and disposal was needed for all the 81 districts to assess the energy generation potential of the same. A sample size of twenty districts was made in view of the obvious constraints in a field survey of the entire study area. These 20 districts were chosen on the basis of data available for the Yamuna basin in one of the recently concluded TERI study (TERI 1998). A stress map (Map 1.2) had been generated in the study which classified all the 81 districts into 3 categories- highly stressed, medium level stressed and lowly stressed. The stress factor was calculated using a number of parameters- population density, number of industries operational in the area, ground water development, groung water fluctuation etc.. Following the same classification, it was decided to take a wide gamut of districts with a focus on highly stressed ones.

During the initial surveys it was found that a large number of district offices did not maintain adequate records and hence they were unable to provide required information. Further, each district generally has more than 3 towns/cities. However, the district headquarter officials had information only pertaining to their town for e.g. Panipat district had information only on Panipat town and not Samalkha town which too lies in Panipat district. Thus, either the survey team had to visit all the towns/cities in a district to get complete information about that district or had to restrict itself to the main town. Due to time constraint, neither of the survey team could collect information for all towns/cities in a district. Though where ever possible, it did try to collect information from maximum number of towns in districts visited. It was also observed that at few places, the officials were reluctant to hand over the information to the field team. In view of all these limitations and after analyzing the collected data from 13 districts surveyed it was decided to discontinue with the rest of survey.

Henceforth, the study objectives were accomplished by secondary data collection from literature and consultation with leading subject experts in all the three areas- municipal waste, sewage and industrial effluents. These have been discussed in detail in each of the individual chapters of the report. Further, it is important to mention here that the energy potential calculations in subsequent chapters have been done considering AD as the most appropriate environmenatlly sustainable energy recovery option.



Map 1.2 Stress zones in Yamuna river sub-basin in 1997

2 Municipal solid waste

The municipal solid waste (MSW) management system of most of Indian urban habitats is in shambles today, owing to pressures exceeding the carrying capacity of the system, resulting in serious environmental hazards. However, the rural centers of country are more or less self sustainable in context of management of waste generated by the residential population due to the nature of waste generated (largely organic) and the indigenous ways, prevailing since long to dispose off the same. It is in for this reason that rural population has not been accounted for in the subsequent sections for final energy generation potential calculations.

Data collection

As mentioned in the methodology section of the introduction chapter, 13 of the 81 districts lying in Yamuna basin were visited and the municipal officials were met to discuss the solid waste management (swm) system in their areas and also to get the data on the same. The most common feature of all the 15 towns visited in 13 districts was that neither of them had a proper collection and transportation system and disposal of waste was the given the least attention by the authorities. Almost all of them were dumping the town waste either outside or within the city limits. There was no fixed site allocated for dumping the waste. Further, neither of the municipalities have ever got an actual survey done to estimate the waste generated and collected in their areas except for Panipat town where a non-governmental organization had conducted this exercise in the past for a Government of India sponsored project. As a consequence, figures provided by the municipal authorities to the field team in most of the towns/cities were based on their approximate calculations of no. of trolleys carrying the waste, carrying capacity of each trolley and no. of trips made etc. This meant that the figures provided were of waste collected and since the waste collection efficiency was far below hundred percent, the actual waste quantum generated was much higher. However there was no means by which the actual quantum generated could be calculated.

Also a questionnaire (Annexure 2) was sent to the municipal officials of all the 81 districts requesting basic information about SWM practices in their districts in the beginning period of this study, but replies were received only from 2 districts.

Table 2.1 gives the information collected from 17 towns in total by the field survey and from the questionnaire response received. The population figures used here are those of 1998 and are projected figures calculated using the population growth rates (CMIE 1993) for individual districts. The projected

figures have been used as only 1991 figures were available from the officials records, but these cannot be naturally considered as the waste collection figures pertain to the current year i.e. 1998.

Table 2.1 Primary survey data

State	*District*	*Town/city*	*1998 Urban population* (projected)	*Waste collected* (tonne/day)
Haryana	Panipat	Panipat	233732	30
	Kurukshetra	Kurukshetra	81255	85
	Kamal	Kamal	204010	100
		Gharaunda	24829	6
	Jind	Jind	85315	80
		Narwana	44414	1
	Gurgaon	Gurgaon	146492	75
Madhya Pradesh	Ratlam	Ratlam	213256	5
	Indore	Indore	1311009	200
	Tikamgarh	Tikamgarh	54173	40
	Gwalior	Gwalior	819982	150
Uttar Pradesh	Allahabad	Allahabad	951507	300
	Meerut	Meerut	876006	200-250
	Agra	Agra	1025090	600
	Kanpur	Kanpur	2225042	1100-1200
Rajasthan	Alwar	Alwar	246795	114
	Jaipur	Jaipur	1820742	700-900

It was tried to arrive at some kind of per capita figures so that the same could be applied to rest of towns of Yamuna basin, however very weird results were obtained upon calculations and hence the data had to be abandoned.

Waste quantum generated

Now, since the field visits were not paying fruitful results, it was decided to bank on the literature available on the concerned subject. National Institute of Urban Affairs (NIUA), New Delhi had published a study in 1989, covering 157 towns then, of which about 25 were the ones considered in the present study. The data had to be discarded as no indicators as to what was the range of MSW generation for towns of different class sizes could be arrived upon and also as the data was too old. Then there was this Urban Sector Profiles report of Rajasthan done by NIUA in 1997, which had a section on MSW, but this report too had figures which did not match well with their class size and population. The per capita waste generated in class 3 towns was coming higher than that in class 2 towns. Since this report too was based on information provided by the municipal authorities to the NIUA, it could not be taken as the ground reality (corroborated by our field experience). There weren't any other reports, papers or studies available on MSW statistics for the Yamuna basin.

Thus lastly, after discussion with several other MSW subject experts of the

country, who have been working in this field for the past several years it was decided to use the per capita figures (Table 2.2) quoted in the National Environmental and Engineering Research Institute (NEERI) final strategy paper on Municipal Solid Waste.

Table 2.2 Per capita waste generation rates

Population range (million)	*Per capita value* (g/day)
0.1 - 0.5	210
0.5 -1.0	250
1.0 - 2.0	270
2.0 - 5.0	350
>5.0	500

Source. NEERI 1995

The paper reports rate of annual per capita increase in waste generation lies in the range of 1%- 1.33%. It also states that this waste generation rate occurs at a rate slightly lesser than the per capita GDP growth rate. In this context Gupta, Mohan, Prasad et al. 1998 have observed that 1.33% figure can be taken as a more practical representation of the waste generation rate vis-a-vis GDP growth rate. Thus the per capita rates were calculated for 1998 considering 1.33% annual growth rate and were further used for arriving at the total waste generation figures for all towns /cities having population more than 0.1 million. The towns/cities having population above 0.1 million are classified as class I towns in India and in Yamuna basin these have 65% of the basin's total urban population. No figures could be found however for the towns having population below 0.1 million and so these have not been considered while making the final energy potential calculations. Table 2.3 and 2.4 give the total waste generation figures for class I towns only. Table 4 includes the towns with population more than 0.5 million, while table 3 has the towns in population range of 0.1- 0.5 million.

Table 2.3 Waste quantum generated by class I towns (population range 0.1-0.5 million)

Town/city	*1998 Urban population* (projected)	*Waste generated* (tonne/day)
NDMC (MC)[a]	401315	87.5
Bhalswa jahangurpur (CT)[b]	126623	27.6
Sultanpur majra (CT)	148603	32.4
Nangloi jat (CT)	101313	22.1
Delhi Cantt.(CB)[c]	125727	27.4
Udaipur (MCl)[d]	355425	77.5
Bharatpur (MCl)	175340	38.2
Alwar (MCl)	246795	53.8
Ajmer (MCl)	456578	99.5
Beawar (MCl)	119460	26.0

Town/city	1998 Urban population (projected)	Waste generated (tonne/day)
Bhilwara (MCl)	210739	45.9
Dehradun (MB)[e]	330235	72.0
Saharanpur (MB)	441750	96.3
Muzzaffarnagar (MB)	289543	63.1
Meerut Cantt. (CB)	111591	24.3
Hapur	193770	42.2
Modinagar (MB)	134681	29.4
Noida (CT)	194104	42.3
Bulandshahar (MB)	144418	31.5
Hathras (MB)	134385	29.3
Ganj Dundwana (MB)	342297	74.6
Mathura (MB)	262189	57.2
Etawah (MB)	142031	30.9
Kanpur Cantt.(CB)	112796	24.6
Orail (MB)	114331	24.9
Jhansi (MB)	352760	76.9
Bonda (MB)	111416	24.3
Fatehpur (MB)	133970	29.2
Simla (M[f])	116336	25.4
Bhiwani (MC)	139044	30.3
Panipat	233732	50.9
Karnal	204010	44.5
Bhind (M)	128077	27.9
Hisar (MC)	199854	43.6
Gurgaon(MC)	146492	31.9
Sonipat(MC)	168640	36.8
Rohtak HUDA	241825	52.7
Sirsa (MC)	133858	29.2
Morena (M)	174526	38.0
Dewas (MC)	197253	43.0
Ratlam (MC)	213256	46.5
Ujjain (MC)	421297	91.9
Mandsaur (M)	110925	24.2
Damoh (M)	111478	24.3
Satna (MC)	184916	40.3
Sagar(MC)	256357	55.9
Vidisha (M)	107990	23.5
Shivpuri (M)	130654	28.5
Guna (M)	122275	26.4
Tonk (MCl)	116467	25.4
Sikar (M)	181367	39.5
Total		2191.7

Note [a]MC: Municipal Committee; [b]CT:Census Town; [c]CB: Cantonment; [d]MCl: Municipal Council.
[e]MB: Municipal Board; [f]M: Municipality

Table 2.4 Waste quantum generated by class I towns (population > 0.5 million)

Town/city	*1998 Urban population (projected)*	*Waste generated (tonne/day)*
DMC (MCorp.)	9599026	4991.5
Kanpur (M Corp.)	2225042	809
Jaipur (MCI)	1820742	511
Bhopal (MC)	1417470	398.3
Indore (MC)	1311009	368
Agra (M Corp.)	1025090	288
Allahabad (M Corp.)	951507	247
Meerut (MC)	876006	227
Gwalior (MC)	819982	213
Faridabad	815613	212
Kota (MCI)	652856	169
Ghaziabad (MB)	601673	156
Aligarh (MB)	570018	148
Total		*8737.8*

Note. For explanation of abbreviations, refer table 2.3.

Calculations were also done assuming 1% annual per capita waste generation growth rate. The total waste generated statistics differed by a meagre 100 tonnes (approximately). This is too small a difference to affect the energy potential as would be evident in the subsequent sections and hence 1.33% growth rate figure seems to be quite reasonable to proceed with.

Energy generation potential

To calculate the amount of biogas/energy generation potential from waste generated by all class 1 urban towns, calculations were done on the basis of laboratory experiments conducted in TERI (Tata Energy Research Institute) laboratories during a previous study in 1996 (TERI 1996). The national average for organic component in the MSW is 40.2% (CPCB 1997). This organic portion has 70%-80% moisture content and 80% of the dry organic matter are volatile solids, on an average 45% of which get converted into the biogas inside the anaerobic digester (Unpublished data TERI). Anaerobic digestion of waste produces energy in the form of biogas, typical composition of which is given in table 2.5.

Table 2.5 Typical composition of biogas

Component	*Value*
Energy content	20-25 MJ/m^3
Methane (CH_4)	55-70% by volume
Carbon-dioxide (CO_2)	30-45% by volume
Hydrogen sulphide (H_2S)	200-400 ppm by volume

Source. Bioenergy 1996

Thus about 70-105 cubic metres of biogas is produced for every one tonne of wet organic waste digested anaerobically. It is important to mention here that the feed for the AD to get biogas of the above order needs to be completely devoid of substances like paper, plastic, stones etc. normally found in municipal solid waste. It should be almost entirely organic matter only. Otherwise the biogas generated would be quite low.

Table 2.6 gives estimates of biogas generation potential along with the LPG(liquefied petroleum gas) heat energy equivalent (on weight basis) for class I towns of the Yamuna sub-basin.

Table 2.6 Energy generation potential of all class I towns

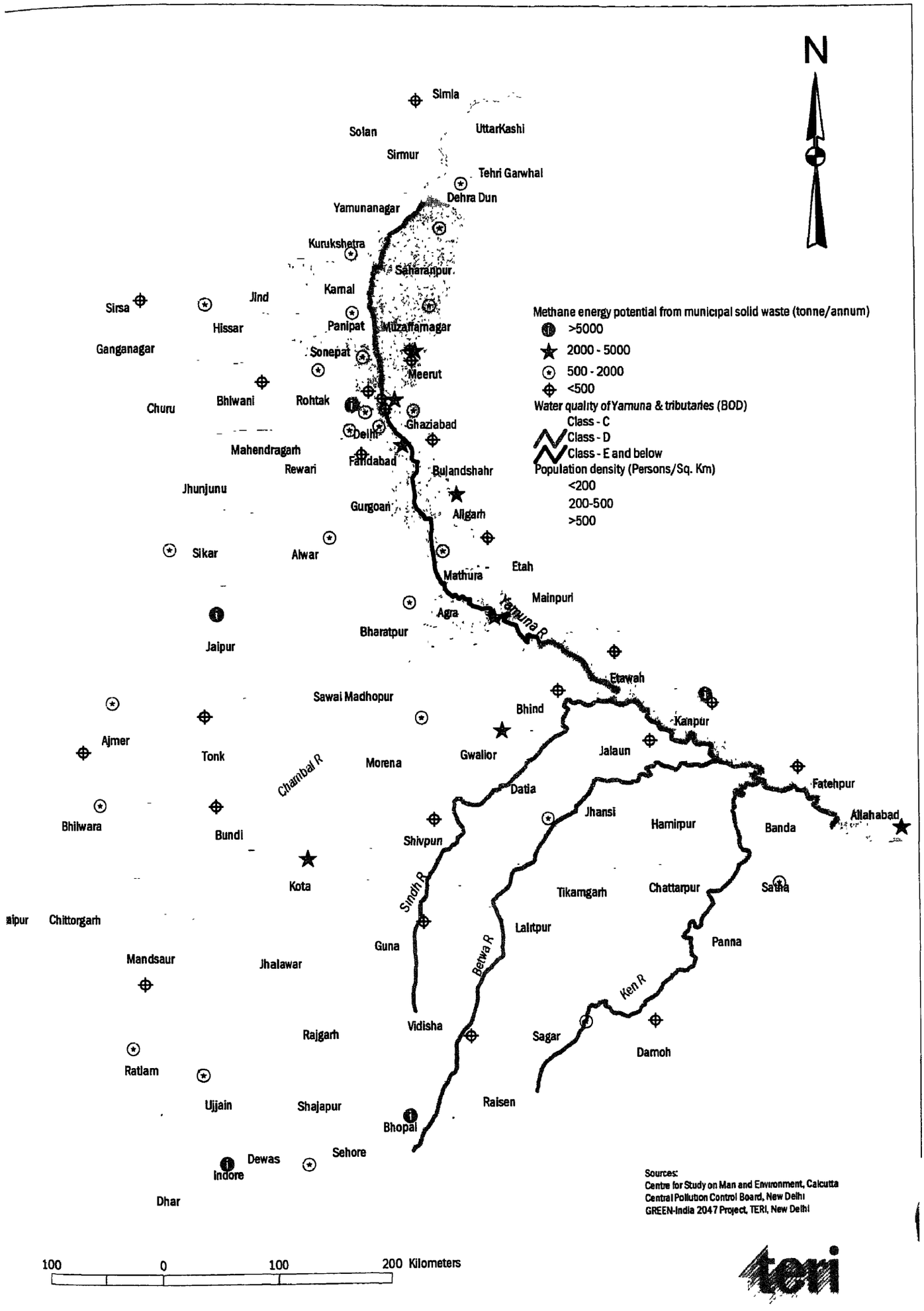
Town/city	*Biogas/energy potential* (m^3/annum)	*LPG equivalent of biogas on wt. basis* (tonnes)
NDMC (MC)	1405.9	593.2
Bhalswa jahangurpur (CT)	426.6	187.2
Sultanpur majra (CT)	520.6	219.6
Nangloi jat (CT)	354.9	149.7
Delhi Cantt.	440.4	185.8
DMC (M Corp.)	80217.1	33843.5
Bhopal (MC)	6401.1	2700.6
Udaipur (MCI)	1245.2	525.4
Bharatpur (MCI)	614.3	259.2
Alwar (MCI)	864.6	364.8
Ajmer (MCI)	1599.6	674.9
Beawar (MCI)	418.5	176.6
Bhilwara (MCI)	738.3	311.5
Dehradun (MB)	1157	488.1
Saharanpur (MB)	1547.6	652.9
Muzzaffarnagar (MB)	1014.4	428.0
Meerut Cantt. (CB)	390.9	164.9
Hapur	678.8	286.4
Modinagar (MB)	471.8	199.1
Noida (CT)	680.0	286.9
Bulandshahar (MB)	505.9	213.5
Hathras (MB)	470.8	198.6
Ganj Dundwana (MB)	1199.2	505.9
Mathura (MB)	918.5	387.5
Etawah (MB)	497.6	209.9
Kanpur Cantt.	395.2	166.7
Orail (MB)	400.5	169.0
Jhansi (MB)	1235.8	521.4
Bonda (MB)	390.3	164.7
Fatehpur (MB)	469.3	198.0
Simla (M)	407.5	172.0
Bhiwani (MC)	487.1	205.5
Panipat	818.8	345.5
Kamal	714.6	301.5

Town/city	Biogas/energy potential (m^3/annum)	LPG equivalent of biogas on wt. basis (tonnes)
Bhind (M)	448.7	189.3
Hisar (MC)	700.1	295.4
Gurgaon(MC)	513.2	216.5
Sonipat(MC)	590.8	249.3
Rohtak HUDA	847.1	357.4
Slisa (MC)	468.9	197.9
Morena (M)	611.4	258.0
Dewas (MC)	691.1	291.6
Ratlam (MC)	747.1	315.2
Ujjain (MC)	1475.9	622.7
Mandsaur (M)	388.6	164.0
Damoh (M)	390.5	164.8
Satna (MC)	647.8	273.3
Sagar(MC)	898.1	378.9
Vidisha (M)	378.3	159.6
Shivpuri (M)	457.7	193.1
Guna (M)	424.5	179.1
Tonk (MCl)	407.9	172.1
Sikar (M)	635.4	268.1
Kanpur (M Corp.)	7795.2	3288.8
Jaipur (MCl)	6378.8	2691.2
Indore (MC)	4593.1	1937.8
Agra (M Corp.)	3591.3	1515.2
Allahabad (M Corp.)	3333.5	1406.4
Meerut (MC)	3069.0	1294.8
Gwalior (MC)	2872.8	1212.0
Faridabad -FCA	2857.4	1205.6
Kota (MCl)	2287.2	965.0
Ghaziabad (MB)	2107.8	889.3
Aligarh (MB)	1997.0	842.5
Total	*175722.1*	*74137.1*

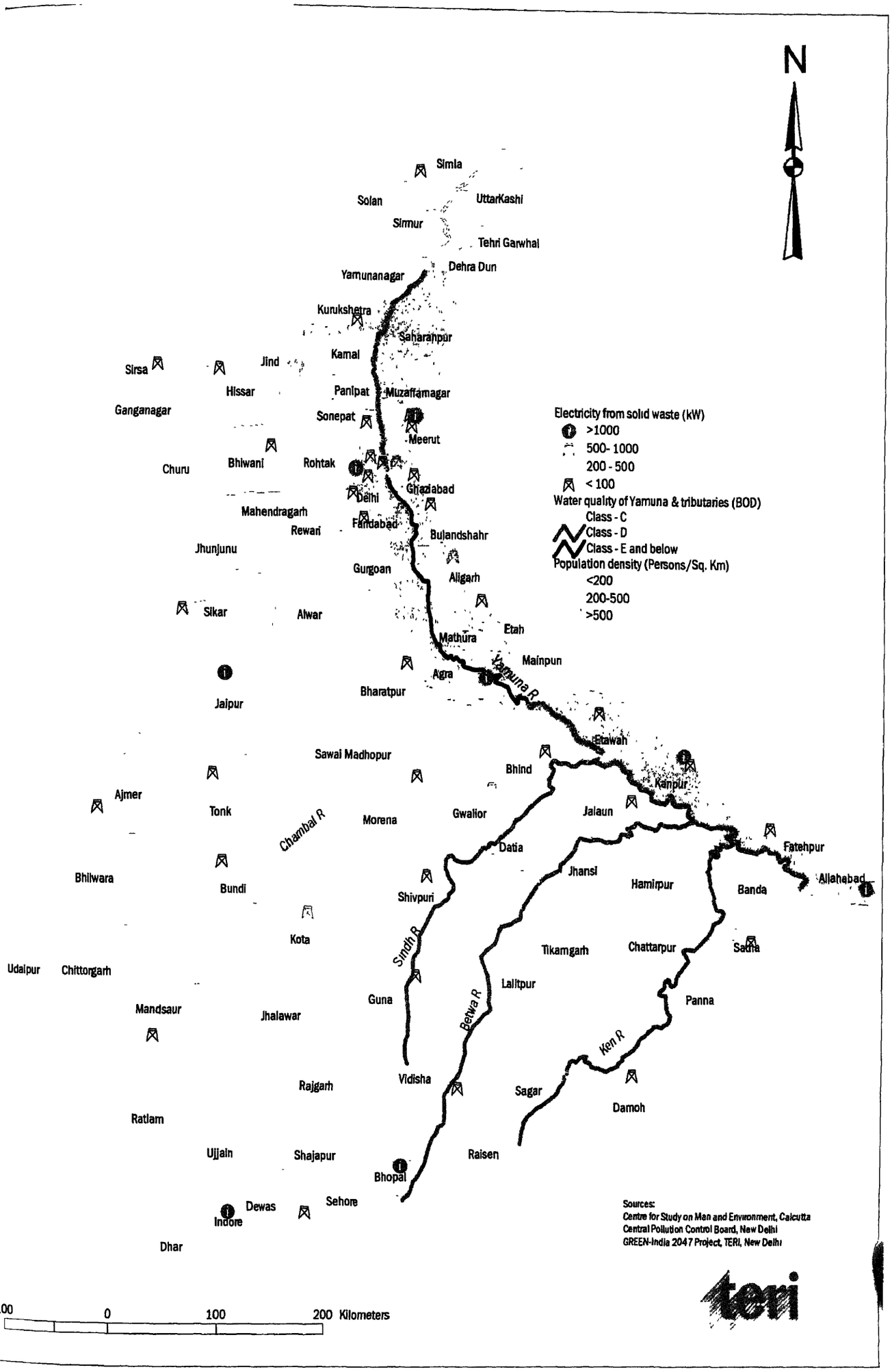
*Note.*For explanation of abbreviations, refer table 2.3.

Map 2.1 gives the graphical representation of energy generation potential. Population density of the district has been overlaid with energy potential data. As is clear from the map, the population density is highest along the river Yamuna. However for many towns like Etawah, Fatehpur etc. inspite of the population density being highest energy potential is in the lowest range. This anamoly can be explained by the fact that for these towns the percentage urban population is insignificant and so the energy recovery potential is also low. On the same hand certain cities like Bhopal, Indore and Jaipur the energy potential is very high but the population density lies in intermediate range. This can be attributed to the fact that these cities being prime centres of commercial and industrial activities have higher share of urban population and hence higher energy potential.
The energy potential can be usefully converted into electricity (map 2.2) by

adopting appropriate technology such as DG sets or gas turbines. To produce 1 kWh electricity 860 kcal are required as heat input. Taking efficiency of gas turbines (with regenerative cycle) as approximately 30% the potential energy figure was converted into corresponding electricity generation figures.



Map 2.1 Energy generation potential from municipal solid waste



Map 2.2 Potential electricty generation from municipal solid waste

echnology interventions and pollution abatement

The choice of technology for energy recovery from wastes is dictated by such factors as moisture content, percentage of paper/plastic, to what extent biodegradable and non-biodegradable fractions can be segregated, prevailing energy prices and economies of scale. The four common technologies for energy recovery from wastes are

- incineration
- production of RDF (refuse derived pellets)
- landfill gas recovery
- anaerobic digestion

The calorific value of Indian municipal waste being low, incineration is not a suitable option for energy recovery. In fact the Delhi experience showed that because of low calorific value the Indian urban municipal solid waste is not suitable for self-sustained combustion and hence incineration would be uneconomical for energy recovery (Planning Commission 1995).

Pelletization is something which might serve as a good energy recovery technology in the near future. At the moment one pilot plant of 150 tonne/day capacity is operating in the country in Mumbai. Another plant is working in Banglaore. Test analysis has shown that there is a marginal drop in CO_2 emissions with the burning of RDF pellets as compared to coal (Sikka 1997). Heat content of coal and RDF pellets is comparable and the pellets are much in demand by the industry as a substitute for coal. On the energy balance front, input of one unit of energy yields 13 times energy by the production of RDF (ibid). These statistics make pelletization an interesting energy recovery option. However, more research would need to be done before this technology is exploited on a commercial scale.

At present about 90% of the waste in the country and almost 100% of it in the Yamuna basin is being dumped in an uncontrolled manner. Wastes dumped in this way degrade in an anaerobic manner and release landfill gas or 'biogas.' Even when the dumping site is a landfill site specifically engineered to recover landfill gas, the recovery process is not an efficient one, yielding only 30%-40% of the amount of gas actually generated (PRISM 1998) . The balance of the gas is discharged to the atmosphere. Since this landfill gas has about 50% methane, considered to be a greenhouse gas with up to 20 times the harmful impact of CO_2 (which makes up the other 50% of landfill gas), such atmospheric emissions are highly undesirable (ibid). Using the Bingemer and Crutzen approach (1987) it has been calculated that methane emissions of the order of 0.57 million tonnes a year will be added to the atmosphere, due to the open dumping practices being followed currently by the class I towns lying in Yamuna sub-basin.

Anaerobic digestion involves the same process that takes place naturally

within a landfill but the process is artificially accelerated in a closed vessel. It is a technology worthy of future consideration in view of the associated advantages of being able to make full use of the 'biogas' generated by the feedstock (i.e. waste) in it and minimum uncontrolled green house gas emissions. It has been calculated that energy worth Rs 1200 million (in terms of LPG equivalent) could be generated annually by anaerobically digesting the entire municipal solid waste of all class 1 towns/cities lying in Yamuna sub-basin.

3 Domestic sewage

River systems are crucial linkages between the needs of the population and their development and prosperity. Unfortunately, indiscriminate exploitation of this scare resource in India has led to quantitative as well as qualitative deterioration, affecting the hydrological and ecological cycles. Yamuna river basin is a no exception and several stretches of it are grossly polluted. The Government of India has formulated Yamuna Action Plan to start pollution abatement measures in the river basin. The schemes under the action plan lay emphasis on resource recovery from sewage by virtue of appropriate treatment technology. The various technological options being considered for sewage treatment include Oxidation pond technology, UASB (Upflow Anaerobic Sludge Blanket) technology and aquaculture.

Data collection

Field survey of districts, literature review and discussions with technical experts was done to collate and analyse the necessary available information on sewage load in the Yamuna basin. Secondary data was collected with the help of field survey in 13 districts. During the survey, local municipal authorities, city health department, department of industries, water supply & sewerage boards, state pollution control board and offices of Ganga Action Plan/Yamuna Action Plan were interacted with and requested to provide the necessary information as per the questionnaire prepared (Ref. Annexure 3). About 2 weeks prior to the primary survey, questionnaires (Ref. Annexure 4) were sent to all the 81 district municipalities in Yamuna basin to provide baseline information on domestic sewage in their respective districts. However, replies were received from 2 municipalities only.

The field survey in most of the cases was successful in collecting information on the major urban agglomeration only and there was lack of data for small towns and rural areas in each of the districts visited.

In addition to field survey, simultaneously, literature review and discussion with technical expert groups from Ministry of Environment & Forests (MoEF), CPCB, National River Conservation Directorate (NRCD), NEERI and NIUA was done to corroborate secondary data analysis and provide logical solutions to data voids.

CPCB under the aegis of MoEF has prepared an exhaustive inventory of water pollution in river Yamuna to determine remedial implementation measures under Yamuna Action Plan (MoEF 1990). The inventory published in 1981 is based on the population census held in 1971. Due to non-availability of

districtwise figures for sewage, the methodology adopted in the inventory for determining the sewage load was based on the status of infrastructure public utilities i.e. water supply and sewerage in the towns and rural areas. The criteria used for determining BOD (Biochemical oxygen demand) load used in the inventory is given in Table 3.1.

Table 3.1 Classification of towns based on public utilities provided

Class	*Public utilities available*	*Adopted BOD* (g/capita/day)
A	Sewerage and Organized water supply	50
B	No Sewerage but Organized waters supply	25
C	No Sewerage and no	15

Source. CPCB 1981

From above it is clear that in order to determine the annual BOD loading for a town/city it is necessary to find out its status in terms of water supply and sewerage. The status of water supply and sewerage cover for Class I & II towns, published by Central Pollution Control Board (CPCB 1990a &1990b) was referred to in this regard. The document had status information for very few towns covered under Yamuna basin. An attempt was also made to locate the information in state/district statistical abstracts published by Department of Statistics, Government of India, but unfortunately these abstracts outline water supply schemes only and have no statistics for sewerage systems.

Continuing, the Urban Sector Profiles for different Indian states published by NIUA was scanned for district wise data. This too did not prove to be of much value as only qualitative information is provided in these and of the five states encompassed by Yamuna basin the Profile study was available for only one state i.e. of Rajasthan.

Data analysis

A comparative analysis of data collected from 13 districts by field visits is given in Table 3.2. It can be observed from the table that data collected during the surveys was limited to wastewater generation and waste treatment status only. The sewage characteristics were not available in most of the cases and hence do not appear in the table. It was decided to restrict the field survey to 13 districts, as no specific correlations between town/population size and per capita BOD_5 loading could be determined for these 13 districts.

Table 3.2 Data collected by field survey from 13 districts

State/District	Town	1998 Urban population (projected)	Effluent generated (MLD)	Existing effluent treatment
Haryana				
Panipat	Panipat	233732	24.19	No treatment & discharge into Yamuna via drains
	Panipat HUDA	na	4.50	No treatment & discharge into Yamuna via drains
	Samalkha	22472	1.94	No treatment & discharge into Yamuna
Kurukshetra	Kurukshetra	81255	7.84	Sewage farming on demand & rest falls in a river
	Pehowa	25307	1.70	Sewage farming on demand & rest falls in a river
	Ladwa	22378	3.40	Sewage farming on demand & rest falls in a river
	Shahbad	36203	2.73	Sewage farming on demand & rest falls in a river
Kamal	Kamal	204010	25.58	Sewage farming
	Kamal HUDA	2794	5.58	Sewage farming
	Gharaunda	24829	2.04	Sewage farming
Jind	Jind	85315	2.48	Oxidation ponds
	Safedon	23117	1.98	Sewage farming
	Julana	13168	0.95	Sewage farming
	Narwana	44414	4.00	Sewage farming
Gurgaon	Gurgaon	146492	10.22	No information
Madhya Pradesh				
Ratlam	Ratlam	213256	20.45	Sewage farming
Indore	Indore	1311009	135.00	Used for irrigation after primary aerobic treatment
Rajgarh	Rajgarh	21751	1.60	No treatment & discharge into Newaj river
Gwalior	Gwalior	819982	106.00	No treatment & discharge into tributary of Yamuna
Uttar Pradesh				
Allahabad	Allahabad	951507	90.00	Conventional aerobic treatment - 90 MLD
Kanpur	Kanpur	2225042	40.00	UASB - 36 MLD
Agra	Agra	1025090	130.00	No treatment & discharge into Yamuna via drains

State/District	Town	1998 Urban population (projected)	Effluent generated (MLD)	Existing effluent treatment
Rajasthan				
Alwar	Alwar	246795	195.00	Partial sewage farming & rest discharged into a river
Jaipur	Jaipur	1820742	203.00	Partial aerobic treatment

Now, in view of the data gaps and constraints regarding data availability, it was decided, after discussions with experts working in this field in CPCB, to calculate the annual BOD loadings using the per capita BOD_5 loading as given in Table 1. The per capita BOD_5 loading dynamics assume steady state behaviour since nature of domestic sewage does not undergo appreciable change with respect to growth in urbanisation and industrialisation. On the contrary, per capita solid wastes generation is closely linked with urban lifestyles and habits. CPCB also has been using the criteria given in Table 3.1, ever since to prepare the water quality statistics for Indian aquatic systems, as generally districtwise sewerage data is not available (Personal communication, Dr R.C Trivedi, Senior Scientist, CPCB).

It is important to mention here that, criteria for per capita BOD loading has a certain ambiguity associated with it. A town with either 10% or 90% sewerage cover would always be categorised under Class 'A'. This kind of ranking structure would give energy potential estimates on a higher side but in view of the rapid infrastructure growth and institutional strengthening, the estimates would hold true in due course of time. Towns (Class I &II) for which published data is available their ranking was based on actual data and for rest it was assumed that Class I towns would be ranked under 'A' category, Class II towns under 'B' category and Class III and below towns would be 'C'.

Energy generation potential

Amount of organic material is a measure of the methane generation potential from wastewater. The yield of biogas (roughly half methane and half carbon-dioxide) is dependent on the efficiency of BOD/COD removal by the treatment system.

Anaerobic systems for municipal wastewater treatment are ideally suited for developing countries like India in view of the sharp outfall between power supply and demand. India built its first UASB plant for municipal wastewater in Kanpur under the Ganga Action Plan(GAP). The design parameters of the plant are given in Table 3.3.

Table 3.3 Design parameters for 5 MLD UASB plant, Kanpur

Parameter	*Value*
Design capacity	5 MLD
Hydraulic retention time	6 hours
BOD	200 mg/litre
COD	500 mg/litre

Subsequently, additional plants under GAP have been built in Mirzapur (14 MLD) and Kanpur (36 MLD), respectively. Performance analysis of the three plants constructed for treating municipal wastewater under GAP is given in Table 3.4.

Table 3.4 Performance analysis of operational UASB plants in India

Parameter	*5 Mld, Kanpur*	*36 Mld, Kanpur*	*14 Mld, Mirzapur*
% COD removal	80	24-50	59-65
% BOD removal	77	25-47	58-71
% TSS removal	85	29-73	50-76
Effluent COD(mg/litre)	200	551-730	133-254
Effluent BOD(mg/itrel)	76	220-303	58-84
Effluent TSS (mg/litre)	128	220-825	98-148

Source. TERI 1996 and Tare et al. 1998

The biogas yield from these three plants was around 0.10-0.15 m^3/kg $COD_{removed}$ with an estimated composition as CH_4 75%-80%, H_2S 0.5%, CO_2 5% and N_2 15%-20% (TERI 1996). The BOD_5/COD ratio for untreated domestic wastewater varies between 0.4 and0.8 (Metcalf & Eddy, Inc. 1995). Assuming average BOD_5/COD ratio as 0.6, the density of methane as 0.717 kg/m^3, BOD removal equal to 50% and the potential for anaerobic treatment for domestic sewage as 50% (taking into account the sewage collection efficiency, existing aerobic systems and septic tanks), the methane equivalent of biogas yield comes to be in the range of 0.06-0.09 g CH_4/g BOD_5 load. Using this factor the energy potential for Class I and II towns works out as given in Table 3.5 and 3.6 respectively.

However, one must keep in mind the fact that these energy figures are probably on the higher side. It has been assumed above that the potential for anaerobic treatment of wastewater is 50% of the total wastewater generated. In actual though this would be true for the class 1 cities, the figure would be lower for rest of the towns on account of very low percentage of sewerage cover available currently and presence of significant number of septic tanks.

Table 3.5 Energy potential from sewage for Class II towns

Town	1998 Urban population (projected)	BOD class	Annual BOD (Gg)	CH_4 emissions (Gg)	LPG equivalent (tonne)
Shimla (MC)	93417	A	1.70	0.10	120.50
Kurukshetra (MC)	93529	A	1.71	0.10	120.65
Jind (MC)	98337	A	1.79	0.11	126.85
Fatehabad (MC)	52661	B	0.48	0.03	33.97
Hansi (MC)	69042	B	0.63	0.04	44.53
Palwal (MC)	78123	B	0.71	0.04	50.39
Namaul (MC)	60694	B	0.55	0.03	39.15
Jagadhri (MC)	79555	B	0.73	0.04	51.31
Bahad (M)	63254	B	0.58	0.03	40.80
Dabra (M)	55303	B	0.50	0.03	35.67
Datia (M)	76434	B	0.70	0.04	49.30
Dhar (M)	70907	B	0.65	0.04	45.73
Mhow cantt.	90053	B	0.82	0.05	58.08
Jaora (M)	63959	B	0.58	0.04	41.25
Nagda (M)	92596	B	0.84	0.05	59.72
NeeMuch (M)	99975	B	0.91	0.05	64.48
Panna (UA)	50093	B	0.46	0.03	32.31
Basoda (M)	54367	B	0.50	0.03	35.07
Sehore (M)	84881	B	0.77	0.05	54.75
Ashok nagar (M)	50812	B	0.46	0.03	32.77
Tikamgarh (M)	65279	B	0.60	0.04	42.10
Chattarpur (M)	87814	B	0.80	0.05	56.64
Fatehpur (M)	81205	B	0.74	0.04	52.38
Lachhmangarh (M)	54506	B	0.50	0.03	35.16
Hindaun (M)	71953	B	0.66	0.04	46.41
Karauli (M)	58017	B	0.53	0.03	37.42
Gangapur City (M)	63558	B	0.58	0.03	40.99
Swai Madhopur (MCl)	85431	B	0.78	0.05	55.10
Suratgarh (M)	54824	B	0.50	0.03	35.36
Hanumangarh (MCl)	93853	B	0.86	0.05	60.53
Jhunjhunun (M)	86395	B	0.79	0.05	55.72
Nawalgarh (M)	61266	B	0.56	0.03	39.52
Kishangarh (MCl)	92912	B	0.85	0.05	59.93
Chittaurgarh (M)	81424	B	0.74	0.04	52.52
Bundi (M)	76271	B	0.70	0.04	49.19
Baran (M)	70123	B	0.64	0.04	45.23
Rajgarh (M)	52654	B	0.48	0.03	33.96
Sardarshahar (M)	81886	B	0.75	0.04	52.82
Ratangarh (M)	66371	B	0.61	0.04	42.81
Sujangarh (UA)	85367	B	0.78	0.05	55.06
Churu (MCl)	99371	B	0.91	0.05	64.09
Rishikesh (MB)	54380	B	0.50	0.03	35.07
Dehradun Cantt.	52600	A	0.96	0.06	67.85
Baraut (MB)	78684	B	0.72	0.04	50.75
Pilkhua (MB)	66455	B	0.61	0.04	42.86
Muradnagar (MB)	58815	B	0.54	0.03	37.93

Town	1998 Urban population (projected)	BOD class	Annual BOD (Gg)	CH_4 emissions (Gg)	LPG equivalent (tonne)
Rajapur (CT)	62188	B	0.57	0.03	40.11
Khurja (MB)	91174	B	0.83	0.05	58.81
Sikandrabad (MB)	69247	B	0.63	0.04	44.66
Agra Cantt. (CB)	57192	A	1.04	0.06	73.78
Kasganj (MB)	86167	B	0.79	0.05	55.58
Etah (MB)	89384	B	0.82	0.05	57.65
Vrindaban (MB)	55223	B	0.50	0.03	35.62
Mainpuri (MB)	88690	B	0.81	0.05	57.20
Auraiya (M)	58121	B	0.53	0.03	37.49
Konch (MB)	52529	B	0.48	0.03	33.88
Muranipuri (MB)	51257	B	0.47	0.03	33.06
Lalitpur (MB)	95525	B	0.87	0.05	61.61
Bawana (MB)	60085	B	0.55	0.03	38.75
Kandhla	53332	B	0.49	0.03	34.40
Mahoba (MB)	64921	B	0.59	0.04	41.87
Rewari (MC)	88447	B	0.81	0.05	57.05
Gokalpur (CT)	63203	B	0.60	0.04	42.26
Babarpur (CT)	65514	B	0.58	0.04	40.77

Notes. Annual BOD load = Total population * Per capita BOD loading as per Class (Table 1), CH_4 emissions = Annual BOD load * Methane emission factor (0.06 g CH_4/g BOD_5 load), LPG Equivalent calculation based on calorific value of CH4 and LPG as 12723 kcal/kg and 10800 kcal/kg, respectively.

For explanation of abbreviations, refer table 2.3.

Table 3.6 Energy potential from sewage for Class I towns

Town	1998 Urban population (projected)	BOD class	Annual BOD (Gg)	Methane emissions (Gg)	LPG equivalent (tonne)
Shimla (M+OG)	116336	A	2.12	0.13	150.07
Bhiwani (MC)	139044	B	1.27	0.08	89.68
Panipat	233732	A	4.27	0.26	301.51
Kamal	204010	A	3.72	0.22	263.17
Bhind (M)	128077	B	1.17	0.07	82.61
Hisar (MC)	199854	B	1.82	0.11	128.90
Faridabad-FCA	815613	A	14.88	0.89	1052.12
Gurgaon (MC)	146492	A	2.67	.16	188.97
Sonipat (MC)	168640	A	3.08	0.18	217.54
Rohtak HUDA	241825	A	4.41	0.26	311.95
Sirsa (MC)	133858	B	1.22	0.07	86.34
Bhind (M)	128077	B	1.17	0.26	302.9
Gwalior (MC)	819982	A	14.96	0.90	1057.75
Morena (M)	174526	B	1.59	0.10	112.57
Indore (MC)	1311009	A	23.93	1.44	1691.16
Dewas (MC	197253	A	1.80	0.11	127.23
Ratlam (MC)	213256	B	3.89	0.23	275.09
Ujjain (MC)	421297	B	3.84	0.23	271.73
Mandsaur (M)	110925	B	1.01	0.06	71.55
Damoh (M)	111478	B	1.02	0.06	71.90
Satna (MC)	184916	B	1.69	0.10	119.27

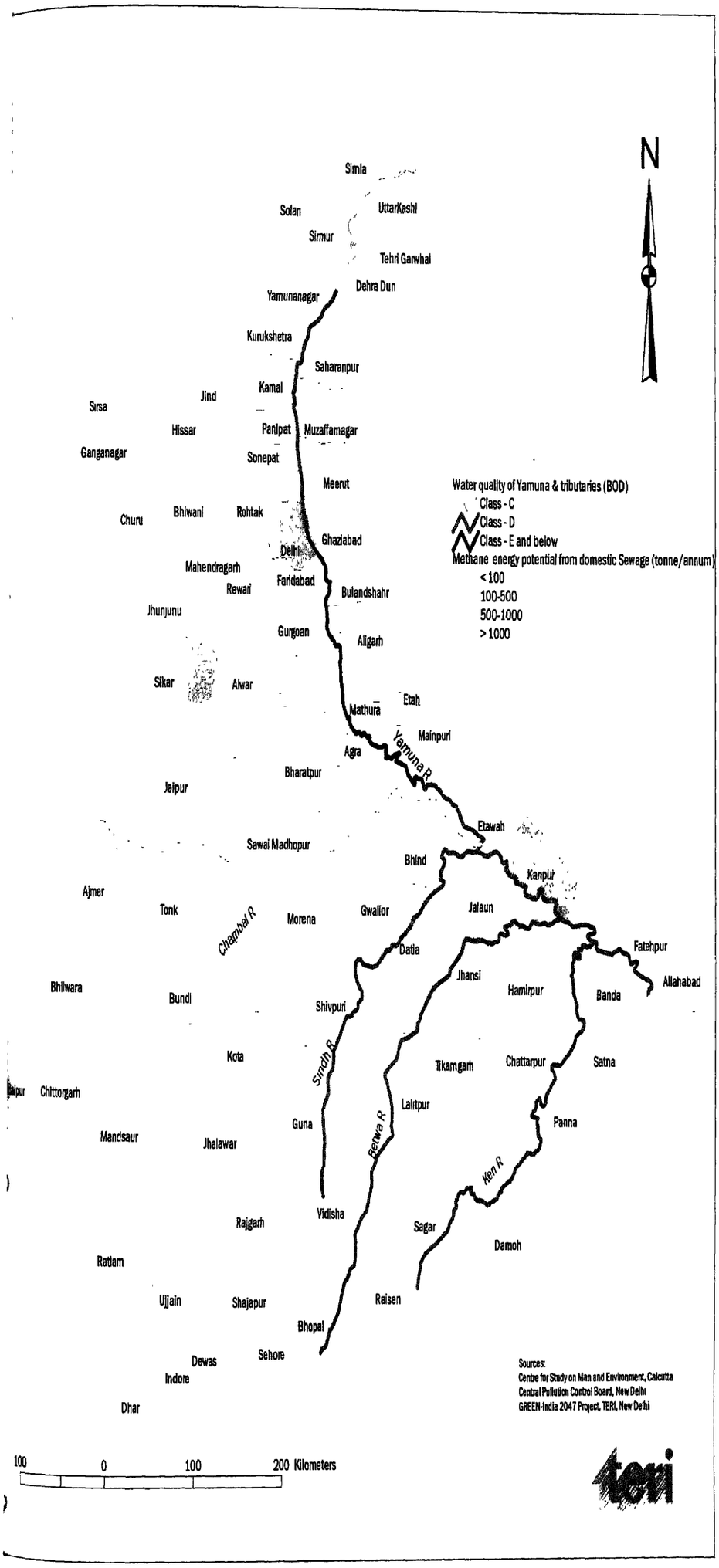
Town	1998 Urban population (projected)	BOD class	Annual BOD (Gg)	Methane emissions (Gg)	LPG equivalent (tonne)
Shimla (M+OG)	116336	A	2.12	0.13	150.07
Sagar (MC)	256357	B	2.34	0.14	165.35
Vidisha (M)	107990	B	0.99	0.06	69.65
Shivpuri (M)	130654	B	1.19	0.07	84.27
Guna (M)	121175	B	1.11	0.07	78.16
Tonk (MCl)	116467	B	1.06	0.06	75.12
Sikar (MC)	181367	B	1.65	0.10	116.98
Udaipur (MCl)	355425	B	3.24	0.19	229.24
Bharatpur (MCl)	175340	B	1.60	0.10	113.09
Jaipur (MCl)	1820742	A	33.23	1.99	2348.70
Alwar (MCl)	246795	B	2.25	0.14	159.18
Ajmer (MCl)	456578	B	4.17	0.25	294.49
Beawer (MCl)	119460	B	1.09	0.07	77.05
Bhilwara (MCl)	210739	B	1.92	0.12	135.92
Kota (MCl)	652856	B	5.96	0.36	421.08
Dehradun (MB)	330235	A	6.03	0.36	425.99
Saharanpur	441750	B	4.03	0.24	284.92
Muzaffarnagar (MB)	289543	B	2.64	0.16	186.75
Meerut (MC)	876006	A	15.99	0.96	1130.02
Meerut Cantt (CB)	111591	A	2.04	0.12	143.95
Ghaziabad (MB)	601673	A	10.98	0.66	776.14
Hathras (MB)	134385	B	1.23	0.08	86.68
Hapur	193770	B	1.77	0.12	124.98
Modinagar (MB)	134681	A	2.46	0.66	173.73
Agra (M. Corp.)	1025090	A	18.71	0.31	1322.34
Ganj Dundwana (MB)	342297	B	3.12	0.07	220.78
Mathura (MB)	262189	A	4.78	1.12	338.22
Etawah (MB)	142031	B	1.30	0.19	91.61
Kanpur (M.Corp.)	2225042	A	40.61	0.29	2870.24
Kanpur Cantt	112796	A	2.06	0.08	145.50
Orai (MB)	114331	B	1.04	2.44	73.74
Jhansi (MB)	352760	A	6.44	0.12	455.05
Bonda (MB)	111416	B	1.02	0.06	71.86
Fatehpur (MB)	133970	B	1.22	0.39	86.41
Noida (C.T.)	194104	A	3.54	0.11	250.39
Bulandshahr (MB)	144418	B	1.32	0.15	93.15
Bhopal (MC)	1417470	A	25.87	1.55	1828.49
Delhi -NDMC (MC)	11213865	A	204.65	12.28	14465.56
Delhi Cantt (CB)	125727	A	2.29	0.14	162.18
Bhalswa Jahangirpur	126623	A	2.31	0.14	163.34
Sultanpur Majra (CT)	148603	A	2.71	0.16	191.69
Nagloi Jat (CT)	101313	A	1.85	0.11	130.69
Delhi-DMC (MC)	401315	A	7.32	0.44	517.68
Allahabad (M.Corp.)	951507	A	17.36	0.06	1227.42

Note: For explanation of abbreviations, refer table 2.3.

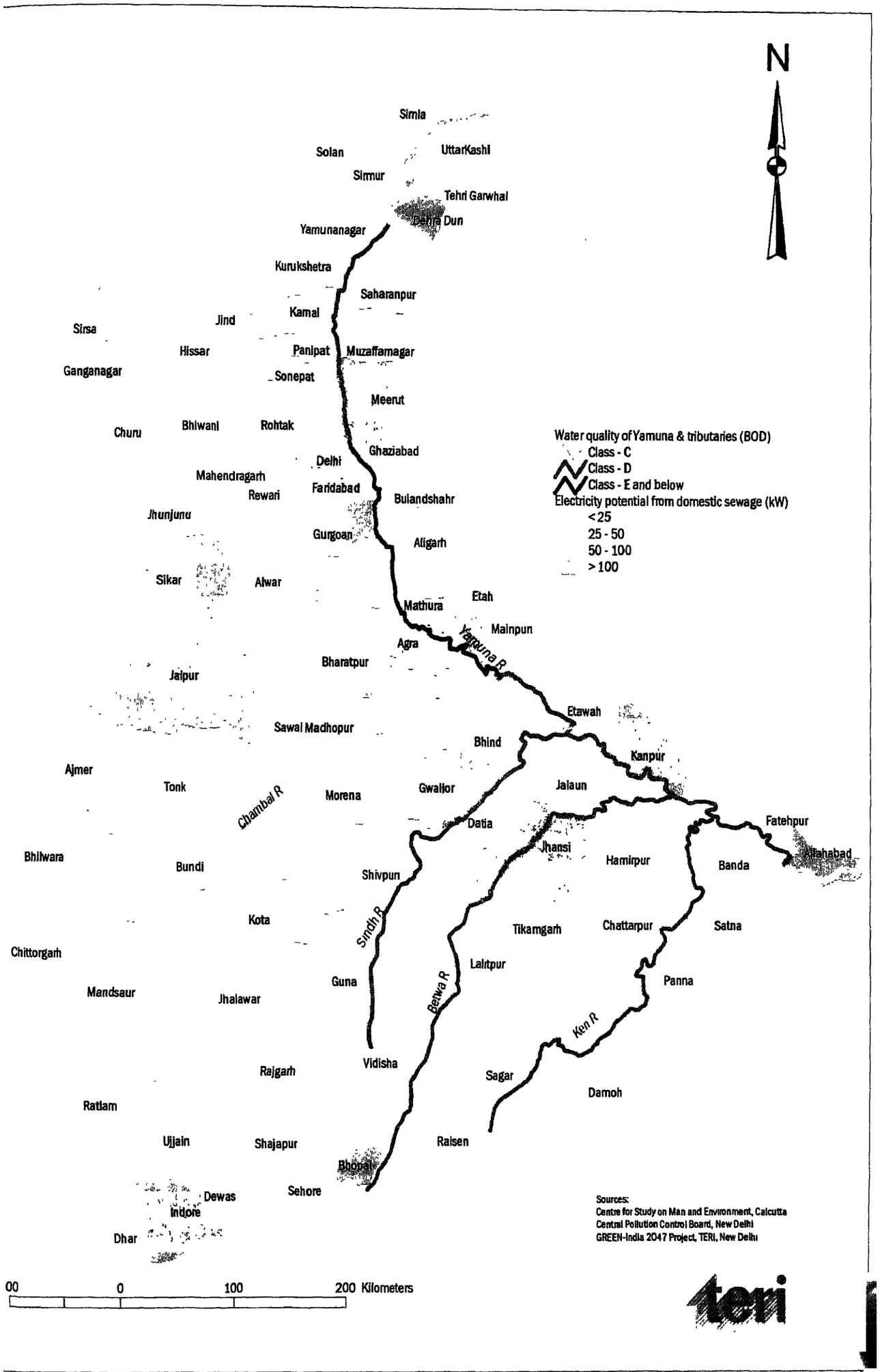
District level spatial representation of energy potential has been made in map 3.1. It can be observed that the districts/ cities of Delhi, Jaipur and Kanpur have the highest energy potential. Delhi accounts for almost 35% of entire basin's total energy potential. This is also corroborated by the fact that the water quality* of river Yamuna deteriorates sharply downstream of Delhi which is largely due to the heavy untreated sewage load being discharged from the city.

Map 3.2 shows the potential of electricity generation (kW) from the methane energy recovered from waste. For arriving at these figures it was assumed that gas turbine technology with regenerative cycle (efficiency ~25%) would be used for converting energy to electricity. A point to be noted here is that the cities of Meerut, Ghaziabad, Delhi, Faridabad, Jaipur, Gwalior, Kanpur etc. have high electricity generation potential (>100 kW) and since all these cities have high congregation of industries, electricity from waste could be an attractive option to partially meet the high power demand.

Water quality classification is as per CPCB 1993 & 1994 publication.



Map 3.1 Energy generation potential from domestic sewage



Map 3.2 Potential electricity generation from domestic sewage

Current status of anaerobic technologies in the Yamuna basin

The Government of India under the Yamuna Action Plan proposed to set up sewage treatment plants with a total capacity of about 1085 MLD. Low cost and environmentally friendly options like use of Raw sewage for Afforestation, Oxidation Pond technology, Aqua-culture and UASB technology were to be encouraged. In view of the resource recovery emphasis, UASB technology would stand out as the best viable option. Presently, a 36 MLD Sewage treatment plant based on UASB is operational in Kanpur and plans are on the fold to construct additional plants in the next five year plan. The details of additional plants is given in Table 3.7.

Table 3.7 Details of additional plants under Yamuna Action Plan

Town	*STP Capacity* (Mld)
Agra	78
Gurgaon	30
Faridabad	115
Sonepat	30
Yamunanagar	35
Panipat	45
Kamal	40

Source. The Yamuna Action Plan, MoEF

It is estimated that 11000 m^3/day of biogas would be generated equivalent to power generation of 800 KW. An amount of Rs 16 million would be recovered per annum on account of power generation, use of treated effluent for irrigation and sludge as manure.

Technology interventions and pollution abatement

Water contamination caused by discharge of untreated municipal sewage and industrial wastewater causes a health hazard to its denizens and endangers the quality of our natural resources. Additionally, methane is the second most important greenhouse gas after carbon dioxide. Anaerobic digestion technology regulates the uncontrolled methane emissions from polluted waters and simultaneously, reduces the burden of using conventional sources of energy to a certain extent.

The Government of India under Ganga Action Plan and YAP has designed schemes for pollution abatement to be implemented in 15 towns. The emphasis of these programmes as stated earlier would be on resource recovery by appropriate treatment technology. It is expected that implementation of UASB technologies under YAP would be able to treat significant portions of the sewage pollution

load. Pollution abatement in terms of global climatic effects is difficult to quantify at a country level. But the trends for the future are encouraging. Technical know-how on the subject is increasing and research institutions and support groups are becoming more active.

4 Industrial effluents

Any industrial wastewater which is rich in biodegradable organic matter with adequate macro- and micronutrient and is devoid of toxic compounds is suitable for energy production by anaerobic treatment. There are a wide range of industries— distillery, tannery, sugar, edible oil, dairy and pulp & paper the effluent from which has high organic content and hence is best suitable for energy (biogas) production. Biochemical oxygen demand (BOD_5) is a measure of the organic matter content of an effluent. Higher the BOD_5 value, higher is the energy generation potential of an effluent.

For effective anaerobic reactions inside a digester to produce energy, it has been observed that the optimal pH range required by methane–producing bacteria is 6.8 –7.2 (Mudrak and Kunst 1986) and minimum C : N : P (carbon: nitrogen: phosphorous) ratio required is 100 : 2.5 : 0.5 (Somayaji 1992). The optimal temperature range for mesophilic biological reaction to occur is 35–40 °C (Hulshoff 1995). In addition, the effluent should have sufficient quantity of trace elements necessary for cell synthesis (ibid). Effluents satisfying the above criteria can be treated directly by the anaerobic process ; for others, same pretreatment/ corrective measures are required to make them appropriate for anaerobic digestion.

To calculate the energy generation potential from industrial effluents, one requires the effluent generation figures in addition to effluent characteristics etc. As evident from the methodology section of chapter 1 and the analysis done in Chapters 2 and 3, paucity of data was a major problem faced during the entire course of this study. Industrial data were the hardest to get as no records are being maintained by the responsible agencies and pollution control boards. Most of the times the industry is also reluctant to reveal the effluent statistics fearing action by the pollution control board. The best information available in case of Haryana was the industrial BOD loading factors for five districts. However, no details of the nature of effluent etc. could be found and a general energy potential factor could not be applied as these districts had many types of industries each having a typical BOD- energy conversion rate.

Thus it was decided to adopt an indirect route by collating information on production of industries which had strong potential for energy generation by anaerobic treatment. This information too was available only for the districts of paper and sugar sectors for Haryana and edible oil and dairy for Rajasthan.

Therefore the table given at the end of this chapter enumerates the partial energy generation potential of these districts, since there are several other sectors figures for which are not available. In the subsequent sections of this chapter, the

industries mentioned in the beginning where the energy generation potentials are high have been discussed in brief and energy generation factors per ton of product have been calculated. These factors have been arrived at on the basis of data received from the industry itself. A detailed questionnaire survey was sent to about 300 industries and the data sent by them was utilized in calculating the energy generation factors.

Distilleries

Most of the distilleries in India are molasses based. The main process includes dilution of molasses with water followed by its fermentation with cultured and developed yeast. The fermented solution is called wash and contains 6 to 8% alcohol. The ferment wash is distilled (with low pressure steam) to separate alcohol. Rectified spirit or neutral alcohol is obtained as the final product. The residue of the distillation process is called spent wash which is the strongest organic effluent. The typical characteristics of distillery effluent are as follows (TERI 1998) :

Wastewater generation	: 12 - 16 litre/litre of alcohol production
Temperature	: 70 to 95 °C
pH	: 4.0 to 5.5
color	: dark brown
COD	: 90,000 - 110,000 mg/litre
BOD	: 35,000 - 50,000 mg/litre
Total solids	: 80,000 - 120,000 mg/litre
Volatile solids	: 4000 - 9000 mg/litre
Nitrogen	: 900 - 1000 mg/litre
Phosphorus	: 40 - 50 mg/litre
Sulphate	: High

From the above characteristics, the distillery wastewater has very high potential for energy generation. Various high rate anaerobic reactors have been installed in India for treatment and concomitant energy recovery. The suitability of anaerobic reactors for the distillery effluent treatment in decreasing order are fixed bed reactors, UASB and fluidized bed (Kaul, Nandy and Trivedy 1997). However, the effluent needs pretreatment for pH and temperature correction and lime scrubbing of biogas for H_2S removal. The anaerobic processes are able to reduce COD load by 70% and therefore post treatment such as lagoons, oxidation pond etc are required to bring the effluent to discharge standards. The distilleries thus have the potential to generate 0.27 kg LPG equivalent energy from wastewater per l of alcohol production.

Sugar

Sugar industry is seasonal having production for 130 days to 195 days a year. Manufacturing process of sugar consists of juice extraction from sugar cane, heating juice to around 65°C - 70°C, liming and sulphitation, reheating to 100°C, separation of syrup and its treatment with sulphur di-oxide followed by crystallization. Sugar manufacturing process produces wastes such as - bagasse which is normally used as fuel in boilers, press mud which can be used as soil enricher and also for biomethanation and wastewater which needs treatment before discharge. Typical characteristics of sugar mill wastewater are as follows (TERI 1998) :

Effluent generated	: 0.2 to 1.8 m^3/ton of sugar
pH	: 4-7
COD	: 1800- 3200 mg/litre
BOD	: 720- 1500 mg/litre
Total suspended solids	: 670 mg/litre
Total dissolved solids	: 2800 mg/litre
Sulphate	: 300 mg/litre

When sugar cane is crushed for the manufacture of sugar, the residue after filtration of the juice is popularly known as sugar cane press mud. The organic content of the waste is 1,10,000 mg/l in terms of COD and 8,000 g/l in terms of BOD. About 4 t of press mud becomes available for every 100 tonne of sugar cane crushed. A floating dome type plant installed in one of the sugar industry at Maharashtra for anaerobic digestion of press mud is able to produce about 100 l of biogas per kg of press mud. COD removal efficiency was observed as 75%.

Anaerobic treatment of sugarmill wastewater needs pH correction from acidic to alkaline. The suitability of anaerobic reactors for the sugar mill effluent in decreasing order are fixed bed reactors, UASB and fluidized bed (Kaul, Nandy and Trivedy 1997). Sugar manufacturing being seasonal, the reactors needs to be restarted at beginning of every season. However, anaerobic process has an advantage over aerobic processes as the former can be restarted fast. Treatment of sugar mill effluent in a UASB reactor could reduce COD contents by 75-80 percent and the average methane gas recovery is about 0.22 m^3 CH_4/kg $COD_{removed}$ at an average temperature of 34°C and 730 mm Hg pressure (Khursheed, Farooqi and Siddiqui 1997). Therefore a ton of sugar production has a potential of generating 0.19 kg LPG equivalent energy from wastewater if treated anaerobically. In addition, about 16.6 kg LPG equivalent energy could be generated from press mud if treated anaerobically.

Tannery

The tanning process has basically three stages : 1) preparation of hides for tanning which consists of operations such as liming and pickling, 2) tanning proper which is carried out either by using vegetable tannin or inorganic chromium salts and 3) finishing. Typical characteristics of composite wastewater of a tannery are :

Effluent generated	: 30 to 40 litre/ kg of hide processed
pH	: 7.5 to 12.5
Suspended solids	: 2800 -3300 mg/litre
BOD	: 720-840 mg/litre
COD	: 3400 - 5100 mg/litre
Total phosphorus as P	: 1.2 - 5.0 mg/litre
Total nitrogen as N	: 120 - 140 mg/litre
Chlorides .	: 1340 - 4200 mg/litre

The anaerobic treatment of tannery effluent has been successfully tried at pilot scale in India. It is possible to reduce BOD and COD contents by 60% and 70 % respectively in an UASB reactor designed for 12 hours HRT. The biogas yield is 0.15-0.25 m3/kg of COD removed with a methane content of 80% (Rajamani, Suthantharajan, Ravindranath et al. 1995). However prior to the anaerobic treatment, wastewater needs pH correction from alkaline to acidic and removal of chromium (if present). For these, various physico-- chemical treatment technologies are well established and practiced in India.To meet the discharge standards, effluent of UASB process is subjected to aerobic post treatment. Tanneries thus has the potential to generate 0.004 kg LPG equivalent energy per kg of hide processed from its wastewater.

Dairy

The liquid waste from a dairy originate from the following sections or plants : receiving station, bottling plant, cheese plant, butter plant, condensed milk plant, dried milk plant and icecream plant. The characteristics of composite are CPCB (1993) :

Effluent generated :2 litre/ litre of milk processed in case of chilling plant & 4.5 litre/litre of milk processed in an integrated plant

pH	: 5.6- 8
Oil and grease	:68 - 240 mg/ litre
Suspended solids	:28 - 1900 mg/litre
COD	:1120 - 3360
BOD	:320 - 1750

Pilot scale experiments conducted in a 20m^3/day fixed film reactor is have shown that the average COD removal efficiency is about 77% and the methane gas

production at STP is about 0.33 m^3/m^3 of wastewater (Roy and Choudhary 1996). Therefore, the potential of energy generation from wastewater of a dairy industry (considering wastewater production as 3 litre/litre of milk processes is about 0.84 kg LPG equivalent per cubic meters of milk processed. The effluent needs simple post-treatment to meet the discharge standards.

Pulp and paper

Most of the paper mills in India uses Kraft process for pulp making. Indian paper mills can therefore be classified as Large paper mills (having annual production capacity of more than 10,000 tonne) small paper mills (having annual production capacity of less than 10,000 tonne) and small waste paper based mills. Typical wastewater characteristics are as follows (TERI 1998).

Effluent generated : 230 m^3/tonne of paper produced
Temperature : 36-38°C
pH : 6.5 - 8.5
Suspended solids : 300- 700 mg/litre
BOD : 50- 150 mg/litre
COD : 250 - 500 mg/litre
Color : Dark brown

Anaerobic digestion of wastewater needs pH correction and nutrients addition. A UASB based pilot plant installed at Satya paper mills, Punjab, India, is able to reduce COD load by 60- 65 % with biogas yield of 0.4 m3/kg of COD destroyed with 72% methane content (Bioenergy News 1997). Based on this experience, paper mills could generate about 9 kg LPG equivalent energy from its wastewater per tonne of paper production.

Edible oil

Extraction of crude oil from the oil bearing material is called solvent extraction which consists of basically four steps viz 1) preparatory work which consists of cleaning, cooking and crushing of seeds and converting it into flakes; 2) extraction of crude oil by means of the solvent (food grade hexane) followed by solvent extraction; 3) refining of crude oil and 4) deodorization of refined oil. The composite wastewater characteristics are (TERI 1998) as follows :

Wastewater generation : 57 litre/tonne of refined oil production
pH : 5.0 - 10
Oil and grease : 400 mg/litre
COD : 3200 - 6000 mg/litre
BOD : 2100 mg/litre

Anaerobic treatment of wastewater needs pretreatment for pH correction from alkaline to acidic and removal of oil and grease. Assuming 70 % reduction in COD in an anaerobic reactor and methane yield of 0.2 m^3/ kg of COD

destroyed, the energy generation potential from wastewater of an edible oil manufacturing plant would be about 0.34 kg LPG equivalent/ tonne of oil produced.

Energy generation potential

As mentioned in the initial stages of this chapter, limited data availability was a major constraint in the industrial energy potential calculations. It was only possible to get production figures of paper and sugar industry for the state of Haryana and edible oil and dairy sectors for Rajasthan. These though would not give complete potential figures for either one sector or for one state, still are being quoted below in tables 4.1 and 4.2 respectively.

Table 4.1 Energy potential figures for Haryana

District	*Energy potential -LPG equivalent (Sugar)* (tonne/annum)	*Energy potential -LPG equivalent (Paper)* (tonne/annum)
Sonipat	34	342.5
Panipat	-	233.3
Yamunanagar	1366	2609.7
Kurukshetra	-	478.3
Karnal	1	829.0
Rohtak	-	965.4
Faridabad	-	359.7
Gurgaon		-
Rewari	7	-
Mohendargarh	3	-
Bhiwani	-	-
Jind	11	516.8
Hisar	11	112.5
Sirsa	113	-

Table 4.2 Energy potential figures for Rajasthan

District	*Energy potential -LPG equivalent (Edible oil)* (tonne/annum)	*Energy potential -LPG equivalent (Dairy)* (tonne/annum)
Ajmer	-	30.7
Alwar	159.1	91.9
Bharatpur	-	61.3
Bundi	-	-
Bhilwara	78.1	-
Bikaner	-	-
Chittorgarh	49.6	-
Churu	-	-

District	Energy potential -LPG equivalent (Edible oil) (tonne/annum)	Energy potential -LPG equivalent (Dairy) (tonne/annum)
Jaipur	9514.8	-
Jhalawar	-	-
Jhunjhunu	-	-
Jodhpur	-	30.7
Kota	43.4	-
Sawai Madhopur	-	-
Sikar	-	-
Ganganagar	22.3	-
Tonk	12.4	-
Udaipur	53.4	-

Technology interventions and pollution abatement

India generates large quantity organic waste from industries specially the agro based industries, tanneries and slaughterhouses. Much of this waste enters the environment with little or no treatment. Wherever treated, these are subjected to the energy-intensive aeration process. Anaerobic treatment of these waste offers significant advantages over these. The most significant advantages are related to the technology's ability to accommodate relatively high rates of organic loading. Also many organic material that are not oxidized in aerobic process can be reduced by anaerobic process. Therefore, anaerobic digestion will have increase usage in the future. However, any new technology has to face some difficulty in the market even if it has significant advantages over the established ones. This is also the case with anaerobic digestion technology. The problems for introduction of anaerobic digestion technology for wastewater treatment in India are - limited availability of consultants/firm's to implement the technology, little full scale experience, lack of experience operators within Industries to take care of the process, less interaction of the commercial vendors with the research organizations and universities.

Anaerobic digestion offers potential energy savings and is a more stable process for medium and high strength organic effluents as compared to the conventional aeration treatment method. Besides reducing the amount of green house gases by recovering the biogas generated by digestion, substitution of oil and coal with this bio-energy, can result in substantial savings of conventional fossil fuels.

Annexure 1

Basic statistics of the study area

State	District	Area (km^2)	Population in 1991 (million)
Delhi	Delhi	1483	9.42
Haryana	Bhiwani	5140	1.13
	Faridabad	2105	1.47
	Gurgoan	2760	1.14
	Hissar	6279	1.84
	Jind	2736	0.96
	Kamal	1967	0.88
	Kurukshetra	1217	0.64
	Mohindergarh	1683	0.68
	Panipat	1754	0.83
	Rewari	1559	0.62
	Rohtak	4411	1.81
	Sirsa	4276	0.90
	Sonepat	1385	0.75
	Yamunanagar	1756	0.82
Madhya Pradesh	Bhind	4459	1.22
	Bhopal	2772	1.35
	Chattarpur	8687	1.15
	Damoh	7306	0.89
	Datia	2038	0.39
	Dewas	7020	1.03
	Dhar	8153	1.36
	Guna	11065	1.31
	Gwalior	5214	1.41
	Indore	3898	1.83
	Mandsaur	9791	1.55
	Morena	11594	1.70
	Panna	7135	0.68
	Raisen	8466	0.87
	Rajgarh	6154	0.99
	Ratlam	4861	0.97
	Sagar	10252	1.67
	Satna	7502	1.46
	Sehore	6578	0.84
	Shajapur	6196	1.03

Annexure 1

State	District	Area (km^2)	Population in 1991 (million)
	Tikamgarh	5048	0.94
	Ujjain	6091	1.38
	Vidisha	7371	0.97
Himachal Pradesh	Simla	5131	0.617
	Sirmur	2825	0.37
	Sivpuri	10278	1.13
	Solan	1936	0.38
Rajasthan	Ajmer	8481	1.72
	Alwar	8380	2.29
	Bharatpur	5066	1.65
	Bhilwara	10455	1.59
	Bundi	5550	0.77
	Chittorgarh	10856	1.48
	Churu	16830	1.54
	Ganganagar	20634	2.62
	Jaipur	14068	4.72
	Jhalawar	6219	0.95
	Jhunjhunu	5928	1.58
	Kota	12436	2.03
	Sawai Madhopur	10527	1.96
	Sikar	7732	1.84
	Tonk	7194	0.97
	Udaipur	17279	2.88
Uttar Pradesh	Agra	4027	2.75
	Aligarh	5019	3.29
	Allahabad	7261	4.92
	Banda	7624	1.86
	Bulandshahar	4353	2.84
	Dehra Dun	3088	1.02
	Etah	4446	2.24
	Etawah	4326	2.12
	Fatehpur	4152	1.89
	Ghaziabad	2594	2.70
	Hamirpur	7165	1.46
	Jalaun	4565	1.22
	Jhansi	5024	1.42
	Kanpur	1040	2.41
	Lalitpur	5039	0.75
	Mainpuri	2759	1.31

Annexure 1

State	District	Area (km^2)	Population in 1991 (million)
	Mathura	3811	1.93
	Meerut	3911	3.44
	Muzaffarnagar	4049	2.84
	Saharanpur	3860	2.30
	Tehri Garhwal	4421	0.58
	Uttar Kashi	8016	0.23

Annexure 2

Questionnaire survey on solid waste

RESOURCE AND ENERGY RECOVERY: SURVEY ON MSW
संसाधन एवं ऊर्जा का पुनर्निष्कासनः कचरे का सर्वेक्षण

TATA ENERGY RESEARCH INSTITUTE, NEW DELHI
टाटा ऊर्जा शोध संस्थान, नई दिल्ली

1. Name of the municipality: _____
   (नगरपालिका का नाम):

2. City/Town Population: _____
२. (नगरपालिका के अन्तर्गत शहर की जनसंख्या):

3. Area under the service of municipality: _____
३ (नगरपालिका का क्षेत्रफल):

4. Total solid waste generated (per day): _____
४. (कुल कचरे का उत्पाद (प्रति दिन)):

5. Total solid waste collected (per day): _____
५. (प्रतिदिन कचरे का कलैक्शन):

6. Disposal of solid waste (कचरे का प्रबन्धन)

Disposal option (उपाय)	Landfill (please indicate area, distance from the city/town) (लैंडफिल)	Composting (खाद बनाना)	Incineration (इनसिनरेशन)	Any other, specify (_____) (कोइ और हो तो बताये)
Quantity of waste per day (मात्रा प्रति दिन)				

* Please give the unit of the quanity of sewage (कृप्या सीवेज की मात्रा की इकाई अवश्य द)

7. Name of the river or lake, if any, near to the disposal site: _____
७. (उस नदी या तालाब का नाम जा कचरे फेंकने वाली जगह से सबसे नजदीक है)

Annexure 3

Questionnaire survey on sewage

RESOURCE AND ENERGY RECOVERY: SURVEY ON SEWAGE
संसाधन एवं ऊर्जा का पुनर्निष्कासनः सीवेज का सर्वेक्षण

TATA ENERGY RESEARCH INSTITUTE, NEW DELHI
टाटा ऊर्जा शोध संस्थान, नई दिल्ली

1. Name of the sewerage board: _____

१. (जल प्रदाय एवं मल निष्कासन कार्यालय का नाम):

2. Area of the city/town covered under water supply: _____

२. (नगर का क्षेत्रफल जो जल प्रदाय के अन्तर्गत है):

3. Total population served under water supply: _____

३. (नगर की जनसंख्या जो जल प्रदाय के अन्तर्गत है):

4. Quantity of water supplied (MLD) in the city: _____

४. (कुल पेयजल की मात्रा जो नगर में वितरित की जाती है):

5. Quantity of sewage generated in the city: _____

५. (नगर की पूरी सीवेज (मलजल) की मात्रा):

6. Disposal of sewage (सीवेज का प्रबन्धन)

Options (उपाय)	Sewage farms (सीवेज खेती)	Oxidation pond (ऑक्सीडेशन तालाब)	Activated sludge (एक्टीवेटिड स्लज)	Anaerobic treatment (एनअरोबिक ट्रीटमेंट)	Total treated water discharged (ट्रीटेड मलजल की कुल मात्रा)	Total untreated water discharged (अनट्रीटेड मलजल की कुल मात्रा)
Quantity of sewage (सीवेज की मात्रा)						

* Please give the unit of the quanity of sewage (कृप्या सीवेज की मात्रा की इकाई अवश्य द)

7. Name of the water body receiving wastewater: _____

७. (जल के उस स्त्रोत का नाम जिसमें ट्रीटेड/अनट्रीटेड सीवेज अन्ततः मिलते हैं):

Annexure 4

Questionnaire for the field survey

Data Sheet for Field Survey (NEDO project)

TERI, New Delhi

Date:

District .....

Total area

Municipality area

Rural area

Urban area

Total population

Municipality population

Rural population

Urban population

Any other

Municipal solid waste

Administrative body responsible

Waste generated (tons/day)

Municipality area

Any other

Characteristics of waste

Moisture content

Organic content

Paper

Plastic

Waste quantum collected (tonnes/day)

Municipality area

Any other

Waste quantum disposed off (tonnes/day)

Municipality area

Any other

Present mode of waste disposal

Landumping

Any other

Annexure 4

District .....

Land-dumpsite information (area, location, years of operation, levelling of waste done or not, pesticides sprayed or not).

Comments if any

Sewage

Administrative body responsible

Drinking water supply source

Ground water

Canal water

River water

Population served by drinking water supply

Municipality population

Rural population

Any other

Total water volume supplied everyday

Waste water generated everyday

Waste water collected everyday

Waste water treated everyday

Characteristic of generated sewage : *before treatment*

BOD

COD

after treatment

BOD

COD

Sewage treatment mode and details

Receiving body for treated sewage

land

water (canal/ river)

any other

Receiving body for untreated sewage

land

water*(canal/ river)*

any other

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